Defiance Class Sloop:

A New Navy 44

ENS Arvidson
ENS Taylor
ENS Firenze

EN476 – Ship Design II

30 April 2001

Defiance Class Sloop

Executive Summary

"We teach sailing here...for one purpose, to make competent seamen of our midshipmen...We aren't interested in making yachtsmen of them...we send them to sea to learn the fundamental characteristic of the professional seaman; a deep seated humility in the face of nature...(and) to produce the best possible officer for the fleet."

CAPT J. B. Bonds, USN(Ret), Former Director

McCurdy and Rhodes, Inc. designed the current Navy 44 sail training sloops in 1984, and the first boats were delivered to the United States Naval Academy in 1988. These boats have served well and long in their career at the Academy and are now scheduled to be replaced. A naval architecture design team comprised of Midshipmen First-class Arvidson, Taylor, and Firenze designed and tank tested a useable replacement sloop as part of a senior design project in the course EN476, Ship Design II, at the Academy during the spring semester of 2001. Prior to this course, midshipmen Arvidson and Taylor completed independent research on hull materials and deck design. The new design would fill the same roll as the current Navy 44 sloops as midshipmen seamanship training and racing platforms. The effort in this design was to use current technology and first-hand sailing experience to improve a good existing design

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***Defiance* Class Sloop**

Arvidson, Firenze, Taylor

Mission Requirements

General: This circular of requirements is for a modernized and improved Navy 44 sailing sloop. This sailing vessel shall carry midshipmen and officers throughout the east coast providing comprehensive training of midshipmen. The goal is to increase the speed with decreased weight while retaining strength and impact stiffness. Considerations are being made for increased passenger comfort and safety, a more ergonomic deck layout, and improved gear such as electronics and deck hardware.

Size: The Length shall be maintained at 44ft. The Draft shall not exceed 7.5 ft.

Operational Area: Chesapeake Bay area, open ocean throughout the East Coast from Nova Scotia to Bermuda. Must be prepared for a variety of weather conditions.

Endurance/Maintenance:

The vessels will be used every day for ten months within the year. The sloops will rarely have a day off. They will be used for training and for the Varsity Offshore Racing Team. Also, the maintenance will be done at the Naval Station where the turnover for technicians will be about three years. Thus, the equipment needs to have simplified maintenance requirements. Also, off-the-shelf equipment is preferred.

Accommodations: The overnight accommodations should include 2 officers/coaches and 8 midshipmen. There needs to be a galley, head, and sleeping accommodations for at least half of the crew plus pipe racks for the rest of the crew.

Speed: 6.5-7 knots with the engine. 7+ knots under sail.

Hull: Take the original hull and adjust it for increased speed. It must be strong enough to withstand a grounding or collision without excessive damage.

Propulsion: Diesel improvement on the present allowing the boat to maintain 6.5 –7 knots.

Classification: Must meet International Measurements System, Offshore Racing Council, United States Coast Guard regulations Category I requirements for a vessel of its size and purpose.

Decks: Must allow for easy maneuverability, improved safety, and passenger comfort.

Cargo Load: Storage for supplies, equipment and personal gear for 10 people on a trip for one to two weeks.

Tanks: There needs to be tanks for sewage, potable water, fuel, and grey water. These tanks must meet the regulations mentioned above.

Ship Control: There needs to be increased visibility for the helm. The boat should be operable with a 3-man watch section. (this will help when the boats are being moved around from the basin to the Naval Station)

Navigation/Communications:

GPS, radar, modern navigation computer system, weather fax, SSB and other standard radio communications (VHF and HF). Loudspeakers need to be located on deck in the cockpit.

Seakeeping: Must be seaworthy and strong in all weather conditions the boat would experience offshore.

***Defiance* Class Sloop**

1 Introduction

There is currently plans for new Navy 44 sloops to be designed and built for the training of midshipmen both in the Command, Seamanship, and Navigation Training Squadron and Varsity Offshore Sailing Team programs at the United States Naval Academy, Annapolis, Maryland. The new design will increase the performance of the boats in competition with modern offshore sailboat designs while retaining or improving the current Navy 44 structural strength, impact stiffness, and seaworthiness for many years of midshipmen training.

The motivation behind this design comes from three experienced offshore sailors who would like to see a good design made better. The design will be realistic and not be swayed by the politics of the actual design process currently underway.

2 Parametric Analysis

Several sloops of the offshore cruiser/racer class were used in parametric studies to determine the principal characteristics of the new design. It was seen in this study that the current Navy 44 is very heavy with respect to its waterline length and sail area as compared to other boats built during the same time period and today. Keeping in mind the constraints of the sloop design due to the operational area, the overall length and sail area will remain the same, but the waterline length will be lengthened and the overall displacement reduced. The draft, beam, and mast height will also remain the same due to the depth of the Chesapeake Bay, width of the current docking slips, and the height of the Naval Academy Bridge. These parametric studies produced the following principal characteristics of the new *Defiance* class sloop as compared to the current *Audacious* class Navy 44 sloop.

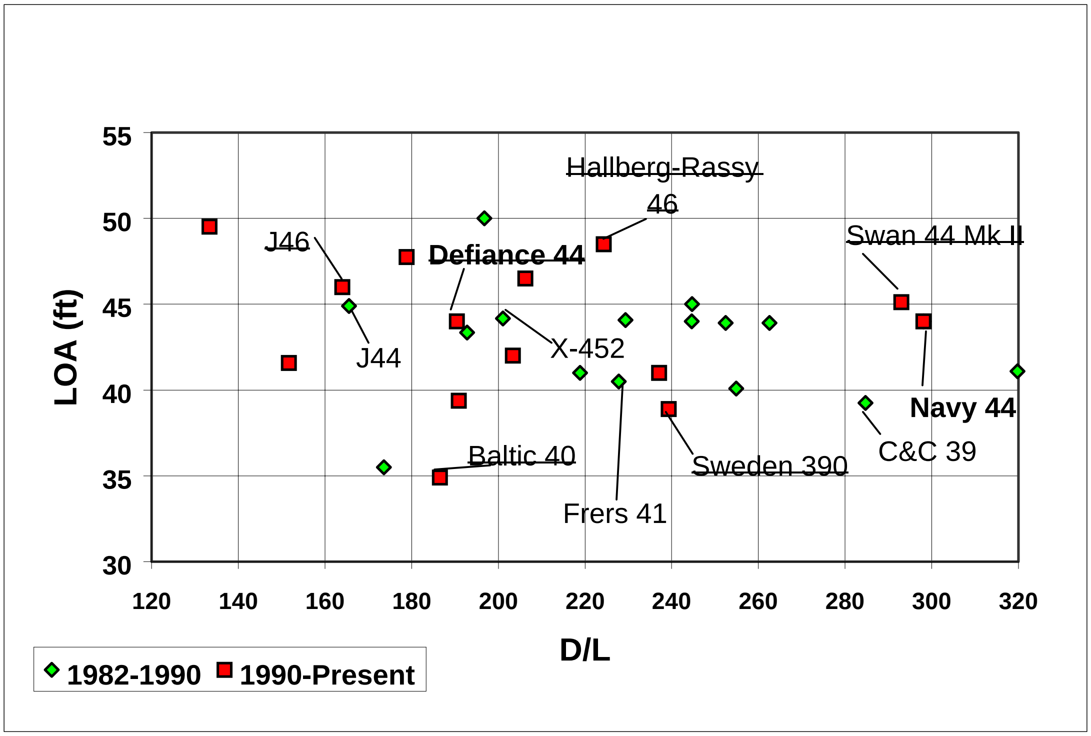

Figure 2.1 Displacement-Length Ratio Plot

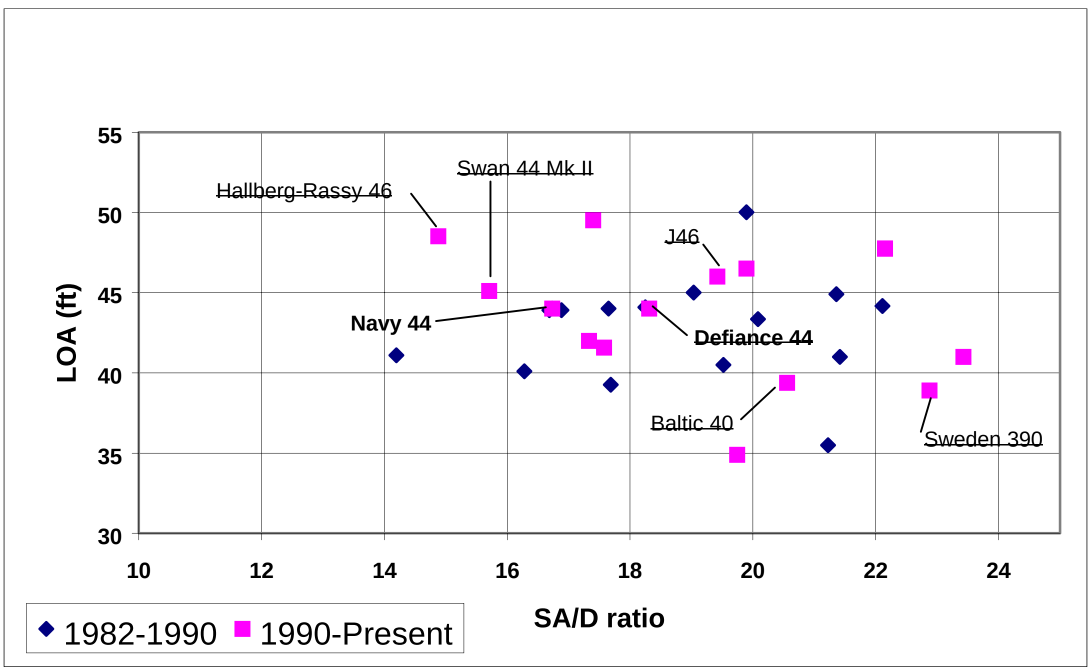

Figure 2.2 – Sail Area-Displacement Ratio Plot

3 Principal Characteristics

Defiance class		*Audacious* class	
LOA:	44 ft	LOA:	44 ft
LWL:	38.4 ft	LWL:	34.6 ft
Beam:	12.4 ft	Beam:	12.4 ft
Draft:	7.5 ft	Draft:	7.25 ft
Cp:	0.56	Cp:	0.56
Displacement:	24154 lbs	Displacement:	27654 lbs
Sail Area:	956 ft^2	Sail Area:	956 ft^2
D/L ratio:	190	D/L ratio:	298
SA/D ratio:	18.3	SA/D ratio:	16.7
Righting Moment at 20 degrees:	48900 ft-lb	Righting Moment at 20 degrees:	34000 ft-lb
Limit of Positive Stability:	142.5 degrees	Limit of Positive Stability:	129 degrees

As seen by these principal characteristics, the *Defiance* class sloop will have greater stability over a wider range of heeling angles. This will improve the upwind sailing characteristics as well as the resistance of the boat to capsize, broach, or knockdown. The sail area-displacement ratio will be greater than the current sloop design, which will improve the light wind performance of the boats, and the displacement length ratio of the new design will be much less than the current design, which will improve the overall performance of the boats.

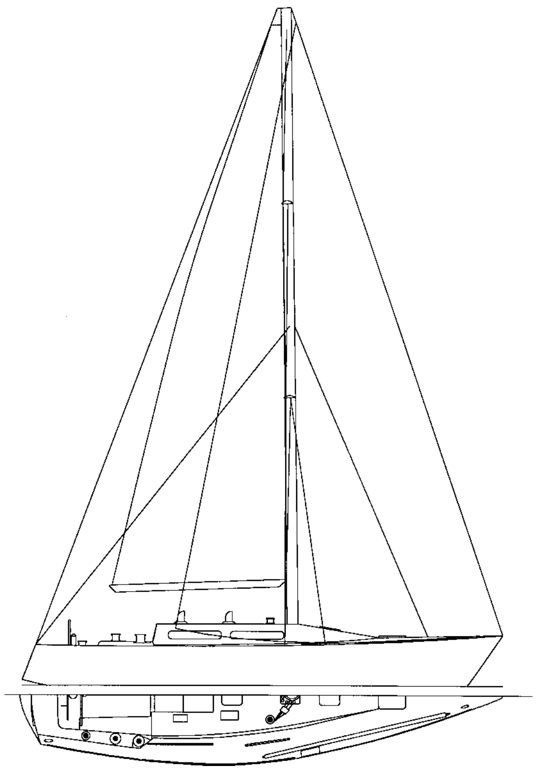

Figure 3.1 - *Defiance* class 44

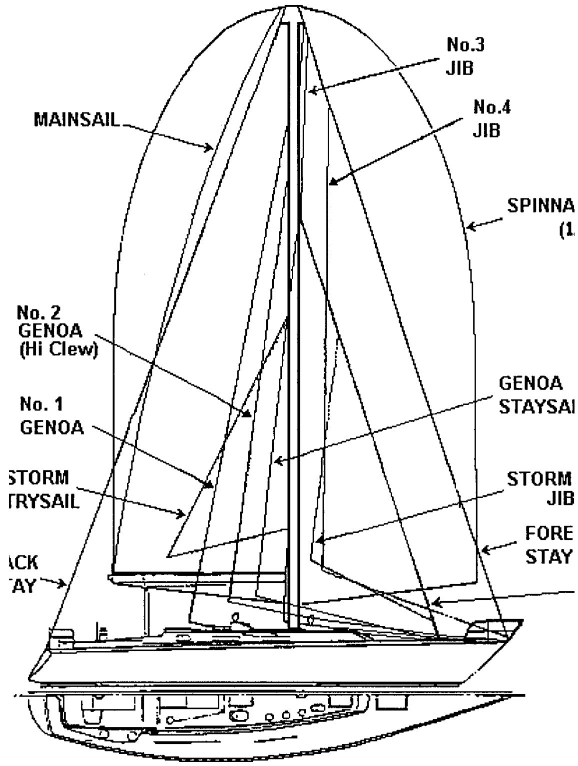

Figure 3.2 - *Audacious* class 44

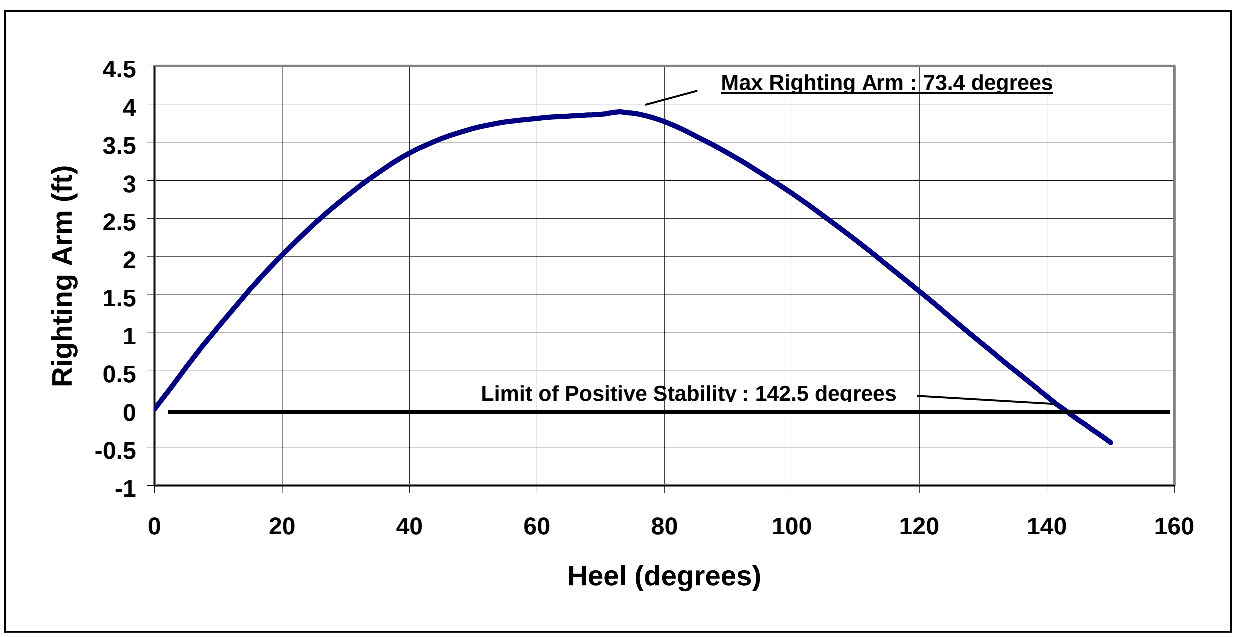

Figure 3.3 – Stability Curve

4 Hull Design

The *Defiance* class sloop hull design was generated using the Fastship 3D computer-modeling program. The current Navy 44 sloop offsets were imputed into Fastship and a surface fixed to them. This surface was then stretched to create the *Defiance* class hull shape, which has a wider stern, shallower canoe body, lengthened waterline, no stern bustle, and roughly the same shear line as the current boat. The knuckle at the bow was drawn below the design waterline to reduce slamming in waves and the bow was raked aft to keep the anchor from striking the hull when anchoring. The stern was widened to increase useable space in the aft part of the interior and to increase the cockpit area.

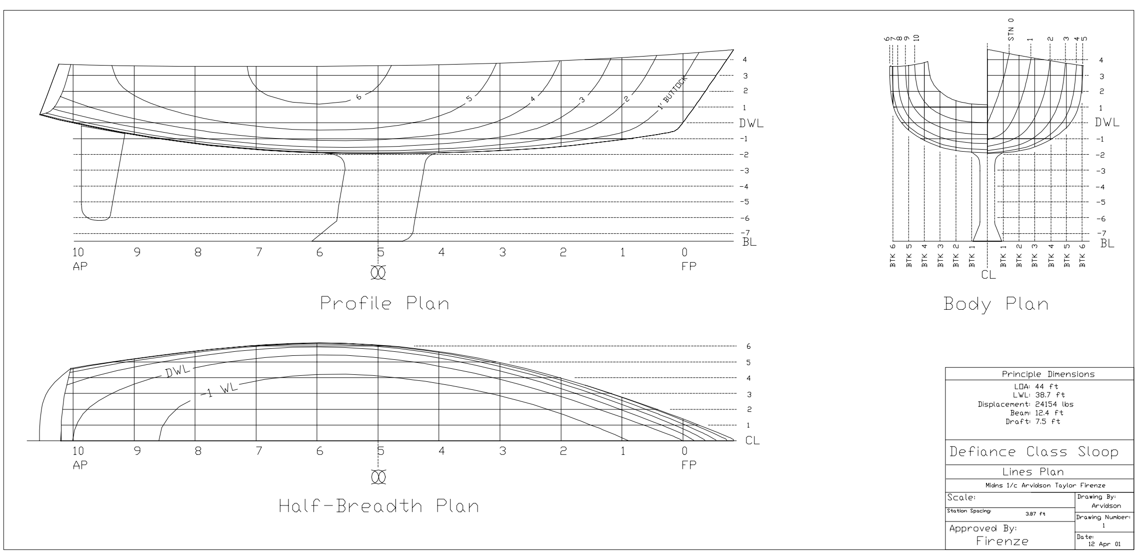

Figure 4.1 – Hull Lines Drawing

5 Keel Design

The keel was designed similar to the design completed by Ensign Aaron DeMyer, USNR, in a study last spring. A lengthy Excel spreadsheet was used with Simpson's Rule to calculate the shape, volume, and weight of the lead keel. The foil section of the keel was designed using a formula that is similar to a NACA 4-digit foil section. The bottom 14.5 inches of the keel is an International Measurements System regulation bulb. This bulb is an equilateral-triangular bulb that uses the same NACA foil section shape as the rest of the keel. The shape of the keel was molded until a weight savings of about two thousand pounds was subtracted from the current Navy 44's keel. This resulted in a 10,282 lb lead keel. The keel will be bolted to the keel stubby using 16 solid bronze, coarse thread, bolts that will be cast into the lead keel. The keel stubby (which is part of the hull) will be twelve inches deep to provide a sump for bilge water and not be too deep to get at the bronze rider plate and bolts that hold the keel to the hull. Honduran Mahogany wood will be used as a spacer between the lead part of the keel and the keel stubby. This spacer will provide and impact barrier between the hull and keel to prevent hull damage due to grounding. The spacer is 6 inches deep from the bottom of the sump.

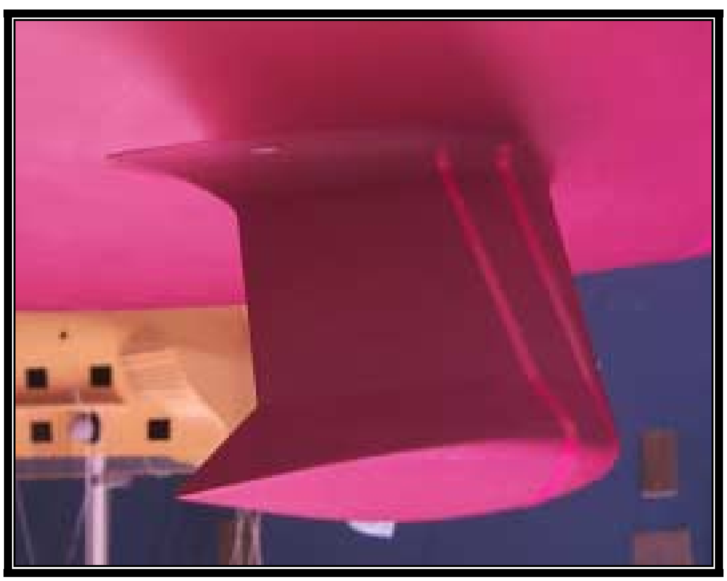

Figure 5.1 – Keel

6 Rudder Design

The current Navy 44 rudder is a low-aspect ratio, skeg-type rudder that pierces the water surface in the stern. To improve the maneuverability of the new boat design, a high-aspect ratio spade-type rudder was designed. By increasing the aspect ratio, we improved the performance of the foil section, thus allowing us to reduce the planform area and therefore reduce drag. The rudder is also completely submerged so there is no air trailing down the rudder reducing the effectiveness of the rudder or leading to premature ventilation. There is no skeg used on the new design to improve the useable rudder area for turning. A significant bronze, stainless steel, or composite shaft will hold the rudder to the hull and will be just as strong as having a skeg for grounding purposes. The rudder was placed as far aft as possible to create the largest turning(yaw) moment.

Figure 6.1 - Rudder

7 Structures

The complete structure of the *Defiance* class sloop is based on topside laminate strength and impact studies that were completed by Midshipman First-class Arvidson during a summer internship with Professor Paul H. Miller.

7.1 Hull Laminate

The topside composite laminate, as determined through the internship (Report EW-10-00 "Navy 44 Sail Training Vessel Design Improvement Projects"), is a symmetric laminate which uses 18/24/18 ounce biaxial knitted cloth stacking sequence on each side of a 0.75 inch thick 6 lb Airex foam core. The resin system used will be Proset 125 epoxy resin system that will ideally be vacuum bagged and post-cured in the fabrication of the hull. The 24-ounce cloth will be oriented at +/- 45 degrees to take the torsional loads in the hull. Below 6 inches above the design waterline is the bottom laminate, which adds one layer of 18-ounce cloth to each side of the symmetric topside laminate. There will be solid laminate, without the core, in the areas of high stress (keel, rudder, engine, and mast) that will extend two inches beyond the longitudinals and 4 inches around the rudderstock. This solid laminate will have an equivalent thickness to the bottom laminate at 0.75 inches.

7.2 Scantlings

All scantling sizes were designed to American Bureau of Shipping standards for Offshore Racing Yachts. The panel just forward of the mast step was used in this analysis as it will have the highest slamming loads as well as the greatest unsupported span. Results concluded the keel floors will be two-inches wide, ten-inches high, using a twenty-pound high-density foam core and ten plies of eighteen-ounce cloth. All other structural members will use a six-pound foam core. The longitudinals will be three-inches wide, four-inches high, with ten plies of eighteen-ounce cloth that will increase in height under the cabin sole. The bulkheads will be one-inch thick with two plies of eighteen-ounce cloth on each side, and the ring frames will be similar to the longitudinals. The longitudinal stringers on the side of the hull will be three-inches wide and two-inches deep and be placed 2.5 feet below the shear line and be hidden by the pipe racks inside. The mast will be stepped on a once-inch thick aluminum plate that will be laminated into the ring frames and set atop a three-inch high glassed-in, plywood-cored, vertical base. The rigging will be attached to chainplates laminated to the main bulkhead to reduce weight and increase strength, stiffness, and reliability. All structures were designed to a factor of safety (FOS) two times greater than the ABS FOS of two.

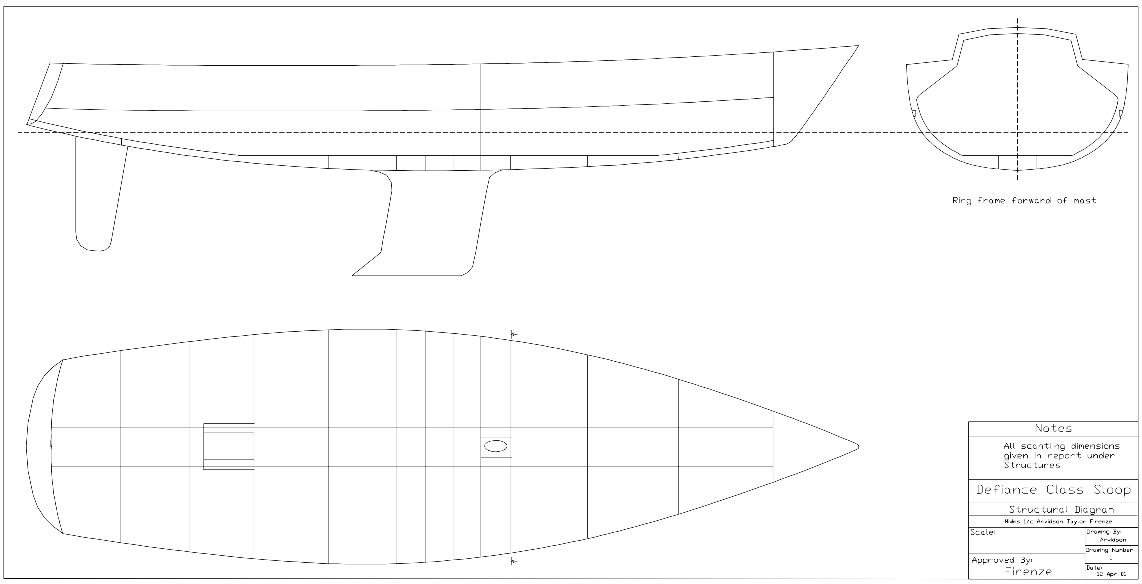

Figure 7.1 - Scantlings

8 Standing Rigging

The *Defiance* class sloop will use a very similar standing rigging to the *Audacious* class sloop. The mast will be an aluminum alloy and stand 62.5 feet above the waterline. Navtec Nitronic 90 rod rigging will be used as it has proven itself on the current Navy 44's even when the mast of one boat hit a bridge. There will be two sets of spreaders swept aft at a five degree angle to better shape the mainsail and simplify the lower shrouds. The backstay will attach to the transom via a split-V configuration to each corner of the stern. A wire will run from one corner, through a block that is attached to the backstay, to a tensioner that is attached to the opposite corner of the transom. This will make it easier to access the transom for man-overboard recovery.

9 <u>Sails</u>

There will be a full compliment of sails made for the *Defiance* class sloops that will be of similar shape and build as the current *Audacious* class sloop sails. The sails will be made of Dacron sail material as it is durable and will last the longest under the high usage and abusage by the midshipmen. The center of effort of the sailplan will roughly be in the same place as the *Audacious* class sloops, and therefore the keel was positioned so that the center of lateral resistance of the *Defiance* class sloop will be in the same place as the *Audacious* class sloop.

10 <u>Deck</u>

An in-depth study was done by Midshipman First-class Taylor to find new ways to make a sailor's job easier on the *Defiance* class sloop. This included interviews with CSNTS and VOST sailors and coaches, locally-based owners of similar boats, and sailmakers. Similarly-sized boats were analyzed, and the J/44 was used as a good example of current design trends. The following is a list of the high points to the new deck design:

Cleats: The present cleats on the bow and the stern will be replaced with "pull-up flush cleats". Presently, lines get snagged in the cleats while underway, leading to potential safety issues. Also, midshipmen are known to injure themselves by tripping on the present cleats. The new type of cleat recesses flush to the deck when not in use, eliminating the hazard. Attwood manufactures this type of cleat and has proven the recessed cleats have equal strength to the existing cleats.

Forward Large Hatch: This hatch now opens so that the hatch cover rests on the deck. In order to do this, the hatch was moved forward and the deck and cabin faired so the hatch is fully supported when open. This position will minimize the likelihood of breakage.

Toe Rail: A standard one-inch toe rail will extend from the bow cleats to abreast the mast. At that point a 5/8-inch T-track will be installed in the middle section of the boat. The standard toe rail begins again at the primary winches and runs aft. The T-track in the middle section of the boat will allow for attaching spinnaker-guy blocks to the rail as well as provide a more comfortable sitting place while racing.

Anchors: In an effort to make the anchors more easily accessible, the anchors will now be housed in watertight compartments on the deck near the shrouds. The anchors will be secured within these compartments. This will, also, eliminate the chance of an anchor being dropped below causing damage to either persons or sails.

Ventilation: The dorades forward of the mast will be removed. VOST and CSTS have discovered the best way to ventilate the boats is by using wind scoops through the open forward hatches while underway. In storms, the dorades would often be rotated aft in an effort to slow the water leakage into the racks; thus, they became less effective. Dorades will be added to the starboard side of the companionway to increase ventilation of the cabin.

Winches and Rope Clutches: Two winches will be removed from the starboard side at the mast. Primarily, VOST sets the jib and spinnaker using the port halyards. The starboard halyards are used more as alternates for a spinnaker peel or mishap. The spinnaker halyard should remain on a winch so that time is not wasted applying pressure to release a rope clutch in the event of a broach.

Companionway: The entrance to the companionway will be recessed back into the cabin housing in an attempt to stop the shower of water that flows into the coach's rack.

Winches: The primary winches will be moved forward since the traveler will be moved aft. The secondary winches will also be shifted forward. The primary and secondary winches will be 3-speed Lewmar racing winches.

Main Sheet and Traveler: The traveler will be moved aft just in front of the helm. This will reduce the hazard of the mainsheet striking a sailor as they exit the companionway in an accidental jibe. The main sheet will now have two winches on either side of the cockpit and the main sheet will be a 4:1 block system.

Helm and stern: The wheel will be moved aft and increased in diameter. The present wheel is slightly small if the helmsman is trying to steer by the sails telltales. By increasing the beam at stern and increasing the wheel diameter, the helmsman can position themselves further outboard thus improving the visibility for the helmsman. To increase forward visibility for the helmsman, the steering platform aft of the wheel is raised four inches. The binnacle chosen is small enough that the main sheet will infrequently get caught on it. Whitlock will supply both the King Cobra steering rack and pin system along with the binnacle as it has a minimum maintenance record and is built for the rudder torque of a Navy 44.

Emergency Tiller: The connection for the emergency tiller will be just forward of the main traveler. The emergency tiller will be the full length of the cockpit which will allow for excellent leverage and protection for the helmsman.

Cockpit and Seats: In the new design, the seats will be narrower and longer and the cockpit floor will be shallower. Since the cockpit will be wider with the increased beam at stern, there will be more room in the cockpit for midshipmen on CSTS or VOST. A foot chock will be added on centerline for a more comfortable ride for the crew while the boat is heeled.

Semi-open Transom: The stern will be open with a step down in the back, and the cockpit coaming will arch in a continuous smooth curve around the stern as a helmsman seat. Under the helmsman seat, the deck floor will drop below the cockpit floor, and the life raft will be secured under the helmsman seat with blocks to keep it from shifting and to prevent the life raft from falling out of the transom prematurely. The life raft will not be secured to the deck with screws. This design will make the life raft more accessible in case of emergency and improve drainage in the cockpit.

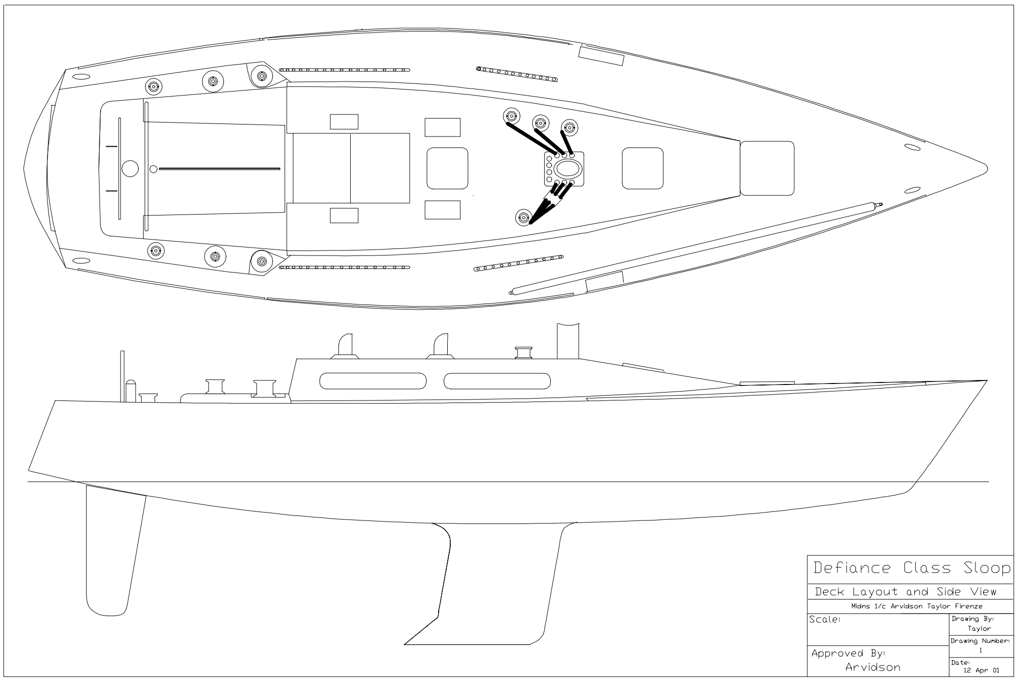

Figure 10.1 – Deck Layout

11 Interior

Sailors of the current boats desire several improvements to the interior. A few of the major concerns are in the areas of berthing, tankage, storage space, improved technologies, livability, and maintenance of the engine.

By lengthening the waterline, the useable space down below in the *Defiance* class sloops will increase. By increasing the waterline length forward, the current pipe berths will be moved forward approximately two feet. This will facilitate the head being moved just forward of the mast to allow for a second quarter berth to be added on the port side. The topside line locker on the port side will be eliminated to allow headroom for the port side quarter berth. The lines in this locker usually drop to the bottom of the locker, leaving several cubic feet of useable space wasted and the lines laying wet on the bottom of the locker. Therefore, line stowage will be moved to the hanging locker opposite the head, where the lines will be hung to dry and be easily accessible.

Moving the head forward has some other great benefits. Now, the engine will be accessible from all sides. The head bulkhead on the current boats is adjacent to the engine cover, making it impossible to access the engine from the port side. This proves to be a frustrating situation as the transmission fluid dipstick on the Westerbeke engine is located on the port side, which makes maintenance very difficult. By clearing the area around the engine, maintenance personnel will be able to better service the engines.

Another area for improvement is the navigation table. The chart table on the current boat does not allow for a whole chart to be flat on the table without being folded. The new angled chart table will allow for an entire nautical chart to be placed unfolded on the table, and a swivel chair will be added for more comfort and to save space over the current design. An overhead rack would house the VHF, HF, and UHF radios as well as the GPS repeater and the weather fax. To the navigator's right will be a docking port for a laptop computer. The new navigation station will be wired for digital communications and will be upgradeable for future technological advances.

The only change in the galley area will be the addition of a small microwave. Most midshipmen experience some degree of seasickness while at sea in these boats, and therefore tend not to use the galley area very much. The microwave, along with a fourth marine battery to handle the increased power load, would allow even seasick midshipmen to quickly heat up hot water for coffee, hot cocoa, or soup, and maybe a toaster pastry or two.

With the decrease in canoe body depth, tankage was moved from the canoe body to under the quarterberths and settees. This facilitated the needed increase in fuel capacity to extend the range of the boats while motoring and eliminated the need to carry jerry cans on deck. A small gray water tank was also added under the cabin sole forward of the engine to comply with no-overboard-discharge ports. Total tankage was increased.

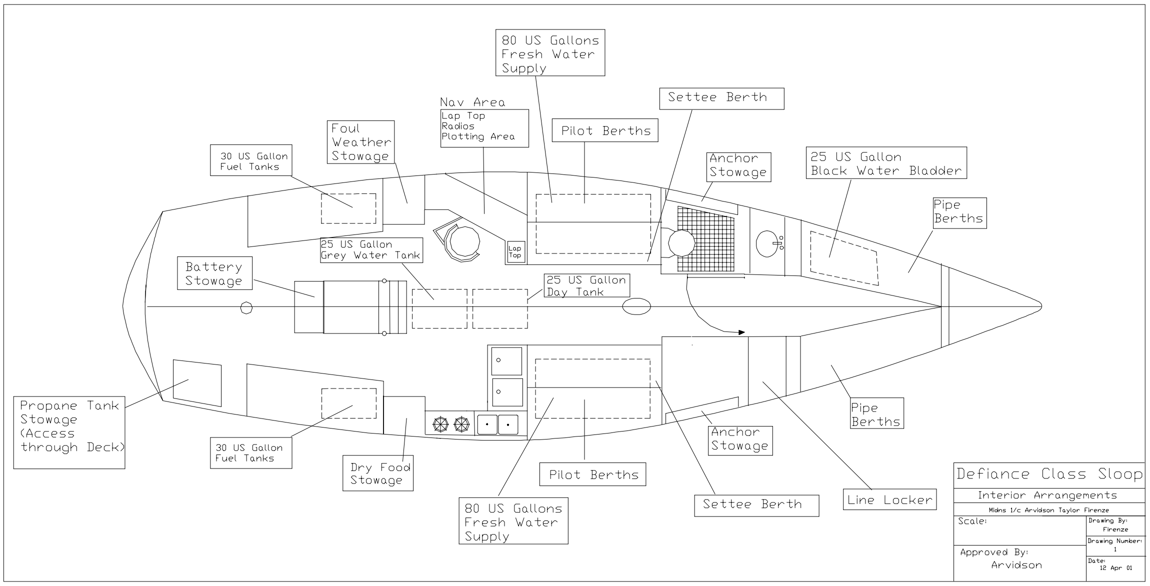

Figure 11.1 - Interior

12 <u>Engine</u>

The current Navy 44, 40-hp Westerbeke diesel engine is underpowered for the boat, which makes it difficult for CSNTS crews to get to their ports if there is not enough wind to sail at six knots. To remedy this problem, a 55-hp 4JH3E Yanmar diesel engine will be installed to push the boat under power at about 7 knots at a constant rated output of 50 horsepower. At this output, the fuel consumption will be approximately 2.5 gallons per hour, but the boat will be able to go faster at higher RPMs than the current Navy 44 because of the less steep resistance curve at higher speeds. The engine will be attached to a Saildrive model 31 with a 19-inch diameter, 18-degree pitch, Max-Prop propeller. The Saildrive will allow for less wasted space in the aft interior, without inhibiting the sailing performance.

13 Tow Tank Testing Results

Two 52-inch models, one of the current Navy 44 and one of the *Defiance* class sloop, were built by Bill Beaver in the TSD model shop for tow tank testing in the 120-foot tow tank at the United States Naval Academy. Resistance testing for EHP expansion was completed on the two models in two days of testing. The models were fully appended and Hama strips were attached to each model to trip the laminar flow to turbulent flow. The data collected from these tests was expanded into an EHP plot comparing the current and new Navy 44. These EHP plots were used to determine the new engine and performance at a wide range of speeds. The resistance plots of both models were expanded to full size and compared to a full-size resistance test that was completed by Ensign Aaron DeMyer and Velocity Prediction Program resistance predictions. It seems the model tests were producing resistances less than expected, by comparing the model and full-size resistance tests of the current Navy 44. The VPP, which was loaned to us by the America One America's Cup Team for use on the Navy 44 new design, predicted that the *Defiance* class sloop will have less resistance at all speeds, not higher resistance at low speeds, compared to the current Navy 44. This disparity in results may be due to the different scaling effects on the foils than the hull in the model tests. Studs, instead of Hama strips, might be tried to improve the model test results.

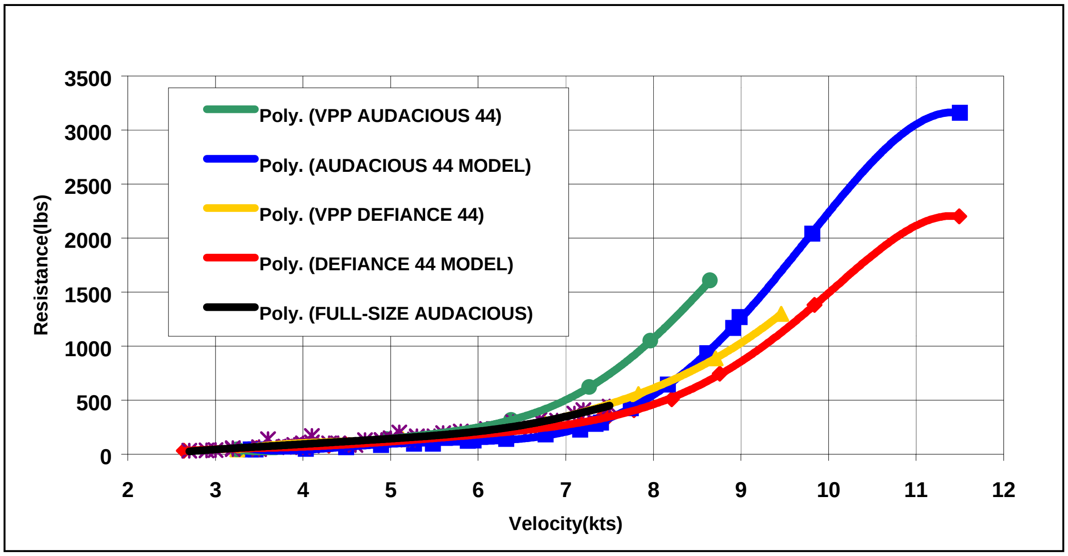

Figure 13.1 – Tow Tank Resistance Test Results (April 2001)

14 Next Iteration

In the next iteration, the beam at stern might be decreased six to nine-inches to reduce the amount of wetted surface area in the stern and reduce the amount of rudder that may stick out of the water when the boat is heeled under sail. There would also be a closer look in to the scantlings to optimize the strength to weight of the boat. A carbon-fiber mast might also be a good idea to further reduce weight and increase stability.

15 Conclusion

The *Defiance* class sloop satisfies the operational requirements of the United States Naval Academy. It also addresses a lot of issues to improve the current Navy 44 design to make life easier for any sailor. We would hope that some of our sailing experience would be used to design a better Navy 44 for the enjoyment and training of midshipmen, officers, and civilians.

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